

# DISINFECTED WATER FOR MILLIONS:

DEVELOPMENT OF THE LOW COST SOLAR DEVICES  
FOR WATER DISINFECTION

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## **Different types of set ups used for solar water disinfection**

- a) Single walled boxes, with and without rim
- b) Double walled boxes with rim
- c) Steel bowl covered with insulating plastic tight fit sheet
- d) Aluminum bowl with insulating plastic tight fit sheet



# MASS INFECTION OF LABOURERS

- It was in Nov. 2009, when I was associated with construction of a building for the local school. On an assigned day, when we had planned to cast a few concrete columns, large number of laborers abstained from work. As the labor contractor informed, all of them were admitted to the hospital and were suffering from diarrhoeal bouts. These families had consumed water supplied in a tanker on the earlier day. It must have been contaminated. This incidence made a deep impact on my mind.

# **POTABLE DRINKING WATER – A GLOBAL PROBLEM**

- MORE THAN A BILLION PEOPLE SUFFER EVERY YEAR FROM WATER BORNE DISEASES.
- ABOUT 4.5 MILLION DIE EVERY YEAR.
- EVERYDAY DIARRHOEAL DISEASES CLAIM THE LIVES OF APPROXIMATELY 5000 YOUNG CHILDREN THROUGHOUT THE WORLD.
- 95% AMONG THESE ARE BELOW 5 YEARS OF AGE.
- MOST OF THE CASUALTIES ARE CHILDREN AND FROM THE UNDERDEVELOPED REGIONS.
- MAKING SAFE DISINFECTED WATER EASILY AVAILABLE IS A REAL CHALLENGE.

# Conventional technologies

Conventional technologies: ozonization, chlorination, and artificial UV radiation.

These technologies are

- capital intensive,
- require sophisticated equipment, and
- demand skilled operators.

At the household level,

- boiling water for about 10 min,
- Use of chlorine chemicals like bleaching powder,
- Add solution of sodium hypochlorite at 1 to 2 drops per lt.

# Limitations of conventional methods

- Boiling water involves burning the precious wood and it will enhance deforestation. It requires about 1 kg of wood/lit of water.
- Chlorine disinfection imparts bad odor. Many do not like it. Inappropriate use and handling of sodium hypochlorite solution poses a safety hazard.
- The ceramic filters need special set up and are costly. They need periodic cleaning and replacement.
- Power operated filter with UV are totally out of reach, especially for the migrant laborers.

# SOLAR WATER DISINFECTION (SODIS)

- Laboratory and field tests have shown that SODIS is 99.9% effective against pathogenic micro-organisms found in water. This may not be as good as boiling which provides pathogen-free sterile water or even pasteurization. In terms of cost, affordability, simplicity and sustainability, SODIS scores over these other methods. Throughout the pilot tested countries, a large portion (81%) of the samples gave a 99.9% disinfection rate.

# Bacterial, viral and protozoan pathogens

- The enteric bacterial pathogens *Salmonella* spp. and *Shigella* spp,
- In aquatic environment and soil *Salmonella* spp. and *Shigella* spp,
- Different groups of viruses, encompassing more than 140, found in the human gut,
- Protozoa associated with waterborne diseases *Giardia lamblia* and *Cryptosporidium parvum* etc.

# The infectious dose

- The infectious dose of *Salmonella* is in the range of  $10^7$ – $10^8$  cells, while some hundred cells only are required to cause clinical illness with *Escherichia coli* O157:H7 and *Campylobacter*. The infectious dose of enteric viruses is low, 90 *HPC and Drinking-water Safety* typically in the range of 1–10 infectious units; it is about 10–100 or fewer oocysts for *Cryptosporidium*

## UV RADIATION FETAL FOR PATHAOGENS

- SODIS reduces the incidence of infectious diarrhoea, dysentery, and also protects against cholera. The sun's radiation is proven to be **deadly to pathogens**, which are used to living in the moist, humid, dark environment inside the body. Once they are discharged into the wider environment, these pathogens are extremely sensitive to conditions outside. UV radiation can be fatal to many such pathogens, while others are **inactivated by maintaining a 50-57°C by** heating in a bottle for a given period of time.

# Bactericidal Effects of Solar radiation

- Bactericidal effects of sunlight is due to **optical and thermal processes**, and strong synergistic effect occurs for **water temperatures exceeding 45°C**. Visible light also effectively disinfects.
- Effect of solar irradiation on five types of pathogenic bacteria, enteropathogenic *Escherichia coli*, *Y. enterocolitica*, *C. jejuni*, *Bacillus subtilis*, and *Staphylococcus epidermis*.
- Some microbial species subjected to SODIS loose the reproductive potential in sunlight.

# Geographical limits for SODIS

- The easy rule is that SODIS works in a “35 degree latitude window,” on either side of the equator that is, the region between 35° North latitude and 35° South latitude. There is plenty of evidence that the “middle” of our planet gets the most direct sunlight.
- The 35° window includes the complete continent of Africa, complete Indian subcontinent and almost all of the places in the world where children suffer from waterborne disease.

# Transmission of UV-A through glass

- Ordinary glass of the soda-lime-silica type can transmit more than 90% of the incident radiation in the **UV-A and visible regions** of the spectrum, provided the  $\text{Fe}_2\text{O}_3$  content is lower than 0.035%;
- Pyrex glass (borosilicate type) is opaque to radiation in the UV-B band and attains a maximum transmission level at 340 nm and beyond. The coefficient of transparency is 0.65 at 330 nm, and attains a **peak level of 0.95-0.99 from 360 to 500 nm**.

# Transmission of UV-A through plastic

- Transparent plastic materials such as Lucite and Plexiglas are good transmitters in the UV and visible ranges of the spectrum. Translucent materials such as polyethylene can also transmit the germicidal components of sunlight.....
- Thus it is possible to use either borosilicate type glass and plastic containers to store water for disinfection.

So in the current set of experiments  
glass bottles and PET bottles were used.

# Advantages of ultraviolet light

- Eco-friendly, no dangerous chemicals to handle or store, no problems of overdosing,
- Universally accepted disinfection system for potable and non-potable water systems,
- Low initial capital cost as well as reduced operating expenses compared with similar technologies such as ozone, chlorine, etc.
- More effective against viruses than chlorine,
- Simplicity and ease of maintenance.

# Effect of Physical parameters

- Container volumes from 825 ml to 2 lt.
- Just heating to 50°C does not serve the purpose. Exposure to solar radiation works.
- Enteric viruses in water can be pasteurized in approximately 1 hour at 62°C or in 1 day at 50°C.
- significant inactivation of *E. coli* occurred within a few hours of exposure, making the 8-hour exposure time unnecessary.
- Dissolved oxygen plays important role. It can be enhanced by vigorous shaking of bottle for about 20 sec.

# **Use of plastic bottles, PET & PVC**

- Various types of transparent plastic materials are good transmitters of light in the UV-A and visible range of the solar spectrum.
- Plastic bottles are made of either PET (PolyEthylene Terephthalate) or PVC (PolyVinylChloride).
- Both materials contain additives like UV-stabiliser to increase their stability or to protect them and their content from oxidation and UV radiation.

# **Effect of sunlight on plastic materials**

- Sunlight does not only destroy pathogenic microorganisms but also transforms the plastic material into photoproducts.
- The UV light leads to photochemical reactions resulting in optical property changes of the plastic material.
- In the course of time, the additives are depleted from the host material by photochemical reaction or diffusion.
- This depletion influences the properties of the material; the UV transmittance in the spectral range of 320nm to 400nm is reduced.

# Risk in Using PET bottles

- PET bottles are preferred over PVC bottles.
- **Plasticizers** from Pet materials **diffuse in water**.
- Quantitative determination of plasticizers di (2-ethylhexyl) adipate (DEHA) and di (2-ethylhexyl) phthalate (DEHP) revealed maximum concentrations of 0.046 and 0.71 micro gm/l, over a period of 17 hr.
- The **17 hr test** duration is **highly inadequate**.
- Secondly the test location is much above the SODIS window of 35° North and South.
- Higher radiation intensity is certain to enhance diffusion of these compounds in water mass.

# 6 hours of exposure in plastic bottle



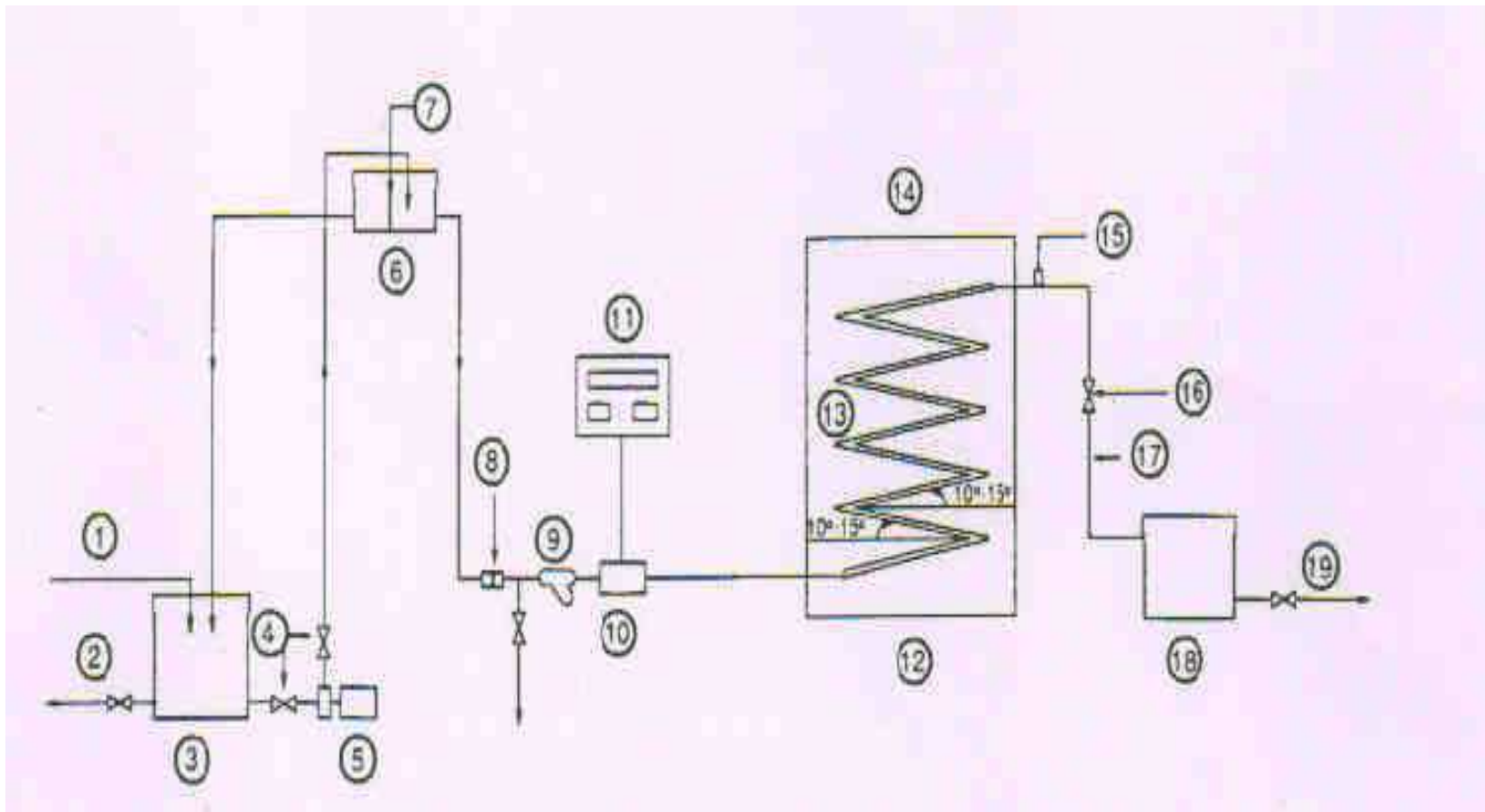
# PET plastic bottles for SODIS

The treated water can be consumed directly from the bottle or poured into clean drinking cups. **The risk of re-contamination is minimized if the water is stored in the bottles.** Refilling and storage in other containers increases the risk of contamination.



## Different types of set ups for disinfection

- **D. A. Ciochetti and R. H. Metcalf (1984):** They fabricated a special **deep solar cooker** to accommodate several water jugs of 3.7 lt each. The high temperature of the order of 65<sup>0</sup>C ensured complete disinfection of contaminated river water.
- **Acra et al (1989):** Acra et al had experimented with two types of layouts of solar reactors, where water passed through a helical tube of glass subjecting it to solar radiation for different periods. Bactericidal effects of UV-A radiation found with exposure time up to 66-68 min.



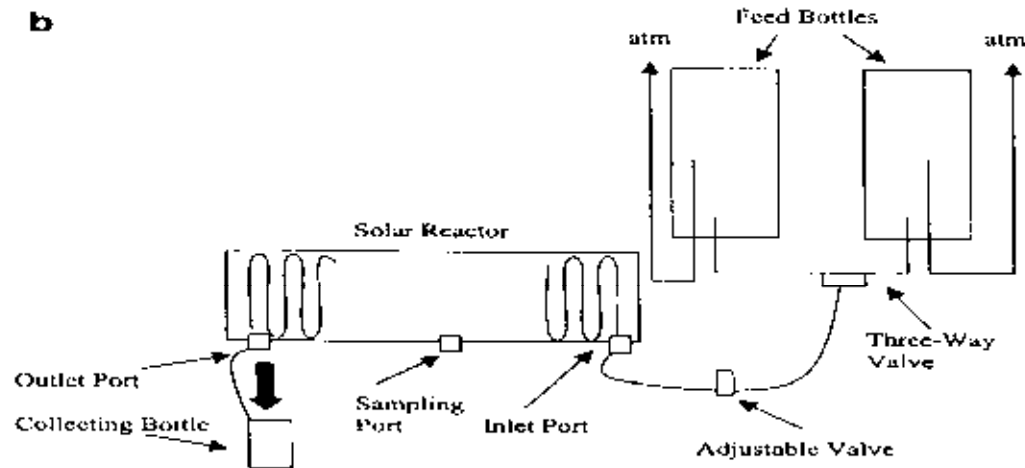
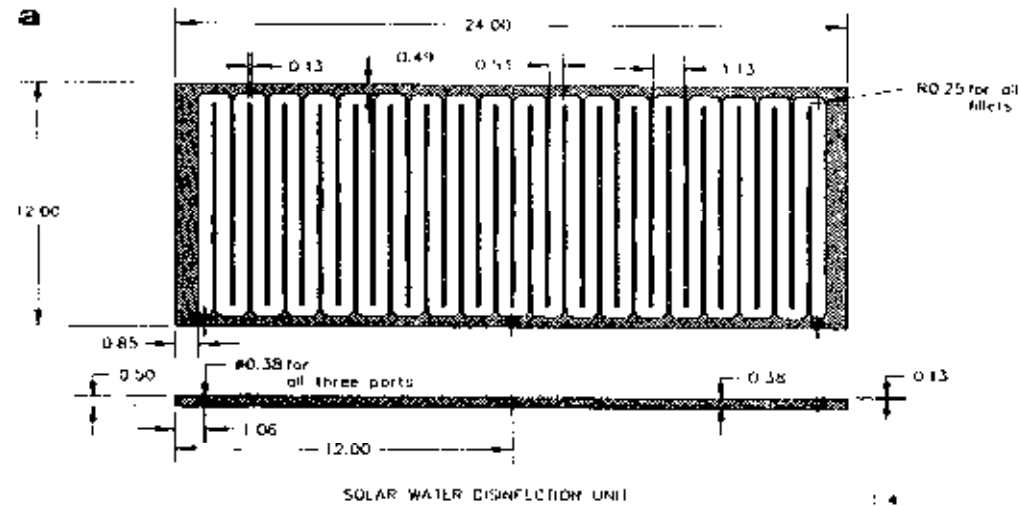
### **Tubular set up type I by Acra et al**

1. Water feed, 3. Storage tank of contaminated water, 5. Pump, 6. Constant head tank, 7. Overflow outlet, 8. Flow regulator, 9. Strainer, 10. Flow meter, 11. Digital meter panel and control, 12. Solar reactor assembly, 13. Serpentine transparent tube, 14. Inclined frame support (facing south), 17. Disinfected water tube, 18. Storage tank for disinfected water.

# Snake type grooved reactor

- **Caslake et al (2004):** It is a set up made out of PVC base with  $\frac{1}{2}$  in wide and  $\frac{3}{8}$  in deep snake shaped grooves compartments. It was covered with UV transparent acrylic plate glued to the PVC base to keep the heat inside. Volume of disinfection unit was approximately 1 lt. The unit was kept tilted about 2.5 cm at the discharge end to avoid air trapping in the passage.
- The final temperatures achieved were of the order of 50°C, 55°C and 60°C for or an average flow rate of 0.4ml/sec of the effluent.
- The unit is portable and can produce about **2 gal of treated water** on a sunny summer day.

# Continuous solar water disinfection set up



# “COOKIT” with reflecting surfaces

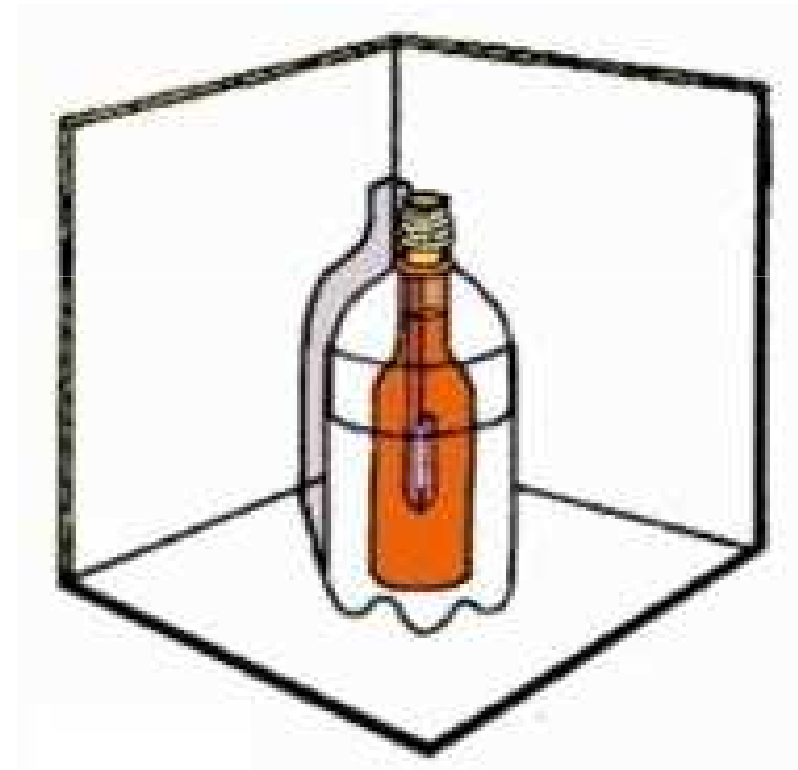
- **Safapour and Metcalf (1999):** At times it is **difficult to achieve water temperatures of the order of 40<sup>0</sup>C and more** where disinfection process becomes effective. It needs additional energy input to the water container, i.e. bottle. Safapour and Metcalf **added reflecting surfaces** to reflect additional solar radiations on the bottles which were painted black to enhance radiation absorption. It consisted of reflecting surfaces made out of cardboard and covered with foiled reflective panels standing at angle to the central bottle. The unit as a whole was called **COOKIT**. It was designed to take **temperature of the black plastic bottle >65<sup>0</sup>C**.
- The researchers also used small device of wax melting at 65<sup>0</sup>C to confirm that higher temperature was achieved

# Cookit reflector model

Cookit kit with blackened water jar



Schematic diagram of Cookit



# **Current trials of family level SODIS units**

**In the current set of experiments, glass bottles and copper jars with least possibility of contaminations are used.**

## **Objectives**

To raise the temperature of water to more than 50°C and maintain it to ensure the deactivation.

Higher temperature rise can be achieved by putting bottles in a transparent enclosure.

Experiments using colorless and colored glass and plastic bottles to check temperature rise.

Copper jars to check oligodynamic effect.

# Selection of bacteria *Escherichia coli*

- *Escherichia coli* is **more resistant to disinfection** than other enteric bacteria and organisms such as *P.aerugenosa*, *S. flexneri*, *S. typhi*, and *S. enteritidis* .
- It may also be **used to determine the likely response of other pathogenic organisms** to a given disinfection mechanism.
- For the current set of experiments *Escherichia coli* was selected for inoculating the water samples **sterilized in autoclave**.

# Dilution Series and Pour Plate Method

- A minimum of 3 dilutions were plated with 4 replicates of each dilution. First, a dilution series was completed in order to dilute the sample to achieve a target count of **30-300 CFU per plate**
- The concentration of viable *E. coli* was enumerated using the **pour plate method** following Method 9215B of Standard Methods.
- The **colonies were then counted** with the naked eye on the lighted background.

# Acrylic box type set up for water disinfection

- As given above several types of set ups batch and continuous flow types have been developed and tested for either bactericidal effect or permanent deactivation of pathogenous bacteria by solar UV radiation.
- The present experimental work deals with batch treatment of water for disinfection at family level by subjecting water to solar radiation in various **simple box type set ups easy to handle** at individual and family level.

# Experiments with acrylic boxes

- Acrylic sheets allow solar **radiation to pass**.
- In order to reduce loss of heat to surrounding and achieve higher temperature of water, acrylic boxes of different types were fabricated from **transparent acrylic sheets 4 mm thick**. These were:
  - a) Single walled boxes with rim,
  - b) Single walled boxes without rim,
  - c) Double walled boxes with rim
  - d) Steel bowl covered with transparent plastic sheet
  - e) Aluminum bowl with transparent plastic tight fit sheet

## **Different types of set ups used for solar water disinfection**

- a) Single walled boxes, with and without rim
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# Effect of putting black paper at the bottom

Two identical double walled boxes were fabricated. These had extended rim at the top.

**Black paper covering the bottom plate prevented heat transmission to the ground** and absorbed all the incident radiation and released it inside the box. That resulted in higher temperature inside the box as well as higher water temperature by about 2°C.



# Comparison of holding capacity of double walled boxes

In order to check the maximum capacity of double walled box, 2 and 3 big bottles of 2.5 lt were placed for heating under identical conditions. It gives same temperature rise. Thus maximum number of bottles can be put for heating in a box

TIME	AMBIEN T TEMP	INSIDE TEMP	DOUBLE WALLED UNIT -1			DOUBLE WALLED UNIT -2		
			L. BRN BOTTLE	L. BRN BOTTLE	L. BRN BOTTLE	L. BRN BOTTLE	L. BRN BOTTLE	L. GRN BOTTLE
9.00	28	SET-2 32	33+	33+	33+	33+	33+	34-
11.10	35	SET -1 45	43	42+	43-	45	45	44
13.50	33	SET - 2 53	54	54	55-	56	56-	56+
15.45	31+	SET -1 53	58	57	58	60	58+	60
17.00	31+	SET -2 53	56	56	55+	58	58	57

# Green house effect in glass and acrylic boxes

The results of heating in **acrylic single walled box, double walled box and glass box are comparable**. Acrylic boxes have advantage of ease of handling. They are unbreakable.



TIME	AMBI ENT TEMP	SINGLE WALLED GLASS BOX			S. W. ACRYLIC BOX		DOUBLE WALLED ACRYLIC BOX			
		INSIDE TEMP	LBB - 1	LBB - 2	LBB - 3	LBB - 4	PET - 1	PET - 2	PET - 3	TRPRNT GLASS BTL
9.15	28+	28	30+	30+	30+	30+	30+	30+	30+	30+
11.15	33+	52	41+	42	42	43	38	38+	38+	40
13.40	35	52	52	52	51	52+	48+	48	48	52
15.40	34	48	57	56-	58	56	51	51	51	55-
18.00	31	37	51	51-	51+	50+	46+	46+	46	49

## Comparison of glass bottles with copper jars

Water in copper jars is heated to higher temperature than in glass bottles. Blackened outside surface of copper jar gives almost 3°C more temperature than the plain copper jar.



TIME	DOUBLED WALLED BOX				SINGLED WALLED BOX W/O RIM			SINGLED WALLED WITH RIM		
	INSIDE TEMP	COPPE R JAR	BLACK COPPE R JAR	LBB W/O REFLE CTOR	INSIDE TEMP	LBB W/O REFLE CTOR	LBB WITH REFLE CTOR	INSIDE TEMP	LBB W/O REFLE CTOR	LBB WITH REFLE CTOR
8:30 AM	25	26+	25+	26	25	25	25	25	25	26
11:00 AM	44	41	46	39	41	36+	36	43	37-	35
13:30 PM	58	50	55	53	48	49	48-	48	49	47
15:35 PM	50	62+	65	61+	40	55	55	44	55	55

# Maximum heat absorption potential

- Simulating cold weather conditions: In the winter season temperatures drop to as low as  $1-2^{\circ}\text{C}$  in north India. So chilled water bottles were kept for heating in double walled box to check the potential of heating and achieving highest temperature.
- By the time temperature exceeds  $50^{\circ}\text{C}$ , it sort of reaches equilibrium with ambient temperature.
- Three bottles with total vol. of 7 lt were subjected to solar radiation. Temperature of water increased from  $1^{\circ}\text{C}$  by  $50^{\circ} + \text{C}$ .

## Comparison of glass bottles with copper jars

The plain copper jar heats up to slightly higher temperature than brown bottle and blackened copper jar heats up to higher temperature by almost  $4^{\circ}\text{C}$  compared to brown glass bottle.

Temperatures in single walled box are consistently at lower temperature than the doubled walled boxes. The temperature profile pattern:

**CJB>CJP>LBB>LTB>PET**



# Checking the maximum heat absorption potential

- Average temperatures in and around Panaji, a coastal town in the State of Goa, India, do not fall below  $20^{\circ}\text{C}$  even in the winter.
- However in other parts of India, in regions away from the sea coasts and in the northern states, the ambient temperatures fall below  $12\text{-}15^{\circ}\text{C}$  in winter.
- In order to check heating potential of the acrylic boxes, chilled water was taken for solar heating.

# Simulating the cold weather conditions

Cold weather conditions were simulated by using chilled water. Heating of water started by 9.00 am. It is possible to start solar disinfection by 8.00 am. It will increase the highest temperature.

Time	Temperature inside box	TEMP IN LTB 1.75 LT	TEMP IN LBB –A, 2.5 LT	TEMP IN LBB –B 2.5 LT
9.30	-	1+	1	1
11.30	43	25+	23+	23+
13.30	55+	40	38	38
14.30	57	46	44+	45
15.30	54+	51	50-	50
16.30	52+	53-	52	53+

# POTENTIAL OF HEAT ABSORPTION IN DOUBLE WALLED BOX

- Combination of 2 LBB and 1 LTB is used for this estimation. That is the capacity of this box.
- Vol. of water in Large Transparent Bottle (LTB) - 1.75 lt
- Rise in temperature from 1<sup>0</sup> to 51<sup>0</sup>C - 50<sup>0</sup>C
- Heat absorbed over the period of solar heating in LTB -  $m \times c_p \times \Delta t$   
- 1.75 X 1.0 X 50  
- 87.5 kcal
- Vol. of water in LBB - 2.5 lt
- Average rise in temperature from 1<sup>0</sup> to 51<sup>0</sup>C - 50<sup>0</sup>C
- Heat absorbed over the period of solar heating - 2 X 2.5 X 1.0 X 50  
- 250 kcal
- Total heat absorption potential for full volume of box - **337.5 kcal**

# Bacteriological studies

- Although it has been reported by several investigators that solar irradiation of clean water for few hours at 50<sup>0</sup>+ C kills or permanently deactivates many types of bacteria. So far nobody has reported use of acrylic box enclosures for raising temperatures of water in bottles.
- Bacteriological testing trials indicate that 5.5 hr exposure to sunlight and temperature rising to 50<sup>0</sup>+ C completely kills *E.- coli* present in the initial sample to the extent of 10<sup>5</sup> -10<sup>7</sup>cells/ml.

# Verification of *E. coli* count by visual method



# **SODIS of water in brown glass bottles**

**Starting with cell count of the order of  $3.0 \times 10^6$   
it reduces to below detection level (BDL).**

Biological testing data				
<b>SAMPLE DESCRIPTION</b>	<b>BOTTLE DESCRIPTION</b>	<b>DILUTION</b>	<b>CELL COUNT</b>	<b>E-COLI/ ML</b>
<b>INITIAL SAMPLE</b>	<b>LBB – A</b>	<b><math>10^{-3}</math></b>	<b>150</b>	<b><math>3.0 \times 10^6</math></b>
<b>INITIAL SAMPLE</b>	<b>LBB – B</b>	<b><math>10^{-4}</math></b>	<b>16</b>	<b><math>3.2 \times 10^6</math></b>
<b>IRRADIATED SAMPLE</b>	<b>LBB – A</b>	<b><math>10^{-3}</math></b>	<b>BDL</b>	<b>BDL</b>
<b>IRRADIATED SAMPLE</b>	<b>LBB – B</b>	<b><math>10^{-2}</math></b>	<b>BDL</b>	<b>BDL</b>

# Direct exposure to the sunlight

Direct exposure to sunlight. Containers kept in open and not in a box. Exposure does not reduce cell count appreciably. Only in transparent glass bottle it is BDL

Biological testing data				
SAMPLE DESCRIPTION	BOTTLE DESCRIPTION	DILUTION	CELL COUNT	E-COLI/ ML
INITIAL SAMPLE	LBB – A	$10^{-4}$	8	$1.6 \times 10^6$
INITIAL SAMPLE	LTB– B	$10^{-4}$	4	$8 \times 10^5$
INITIAL SAMPLE	LGB – C	$10^{-3}$	17	$3.4 \times 10^5$
IRRADIATED SAMPLE	LBB – A	$10^{-2}$	15	$3 \times 10^4$
IRRADIATED SAMPLE	LTB – B	$10^{-1}$	BDL	BDL
IRRADIATED SAMPLE	LGB – C	$10^{-3}$ , $10^{-4}$	DOUBTFUL	DOUBTFUL

# **Solar disinfection of water for millions - I**

- 1. It is possible to achieve temperature of water more than 55°C in transparent as well as colored bottles. It ensures complete deactivation of pathogens and bacteria .**
- 2. Double walled acrylic boxes are more effective than single walled boxes as 5 -7°C higher temperatures are achieved.**
- 3. Heat absorption potential changes with color as follows:  
BLUE > GREEN = approx BROWN > TRANSPARENT >  
GREEN PLASTIC >TRANSPARENT > PET**
- 4. It is advantageous to use transparent acrylic box rather than metallic bowls as acrylic box does not need shifting and reorienting of bottles.**

# **Solar disinfection of water for millions - I I**

- 5. Black insulating paper at the bottom improves performance in terms of higher temperatures achieved and reduction in temperature gradient.**
- 6. Green house effect performance of the single walled acrylic box is comparable with glass box. It is surely better in double walled box.**
- 7. Thin copper jars give higher water temperatures compared to glass bottles. As expected blackened copper jar gives higher water temperatures of the order of 60<sup>0</sup>+ C.**
- 8. As the present set of acrylic boxes are handmade, these are not airtight. In single piece molded box and cover, when mass produced, the lid and top rim of the box can be made airtight. These will give better performance.**

# **Solar disinfection of water for millions - III**

- 9. Although there exists temperature gradient in bottles from top to bottom, temperature rise above 50°C ensures disinfection.**
- 10. Copper jars achieve higher water temperatures compared to glass bottles. Although UV does not pass through copper the oligodynamic effect comes into effect rendering infected water potable. However it needs verification whether it releases more copper in water to be harmful.**
- 11. Potential to absorb heat in both single walled and double walled units of the given size works out at 370 kcal over a period of exposure of 5 hours.**
- 12. It is estimated that the whole set up with glass bottles will cost about Rs 1000.00 which is about a week's earning of casual labourer. The set with copper jars will cost more.**
- 13. These types of set up can be used at army posts on the border. It will be interesting to see whether double walled set up works in areas like Siachin and China border.**

## **Solar disinfection of water for millions - IV**

- This set up will cost about Rs 1200 for a family. It is equivalent to about one week salary of a casual labourer. Use of bottles with small neck prevents possibility of contamination.
- **POPULARISATION OF THE SET UP WILL HELP TO BRING POTABLE DISINFECTED WATER WITHIN REACH OF MILLIONS BELONGING TO THE ECONOMICALLY WEAKER SECTIONS OF THE SOCIETY.**

**Thank you**

Goa Energy Development Agency

Goa